Foundation Design of a Fixed Fuel Station

(Case Study; Niger Delta Region of Nigeria)

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ABSTRACT: *Distribution of petroleum product within the oil rich Niger Delta area of Nigeria is a daunting task because of its deltaic nature. To solve this challenge, fixed fuel dispensing stations will be built in the coastal environment to receive and make supplies available to fishermen and marine transporters. Building of such fuel stations require proper foundation design. Soil test results of the region was obtained and a foundation design was made to ascertain the number of piles pile depth, pile spacing, skin friction, lateral load bearing capacity and end bearing capacity. API codes where used to check and ensure that the results obtained are within safety limits. This will ensure that the offshore structure completes it intended and designed life span.*

KEYWORDS; *FOUNDATION, OFFSHORE, PETROLEUM, PILE, STATION*

I. Introduction

The Niger Delta region of Nigeria is basically known for its enormous oil and gas deposits. This has basically enriched the nation as a major exporter of crude oil. Unfortunately, this success has not been translated into the improvement of the availability of petroleum product for the offshore terrain. In order for the product to be fairly distributed to all the communities around this region there should be the provision of fixed or floating fuel dispensing stations. If this is done, it will greatly reduce illegal activities such as pipeline vandalization and illegal refineries that spread all over the region. These illegal activities have destroyed the eco system of the place. In building a fixed fuel station a proper foundation design must be carried out.

Foundation engineering studies are critical for all structures placed on, founded in, or anchored to the seabed. The impact of the proposed structures has also to be assessed for their effect on other structures and their influence on the local (and regional) environment (e.g., scour).[1]Typically, foundation costs 25 to 34% of the overall costs.[2]and also it governs the capacity of the structural system [3]Therefore, it is necessary to pay detailed attention. The foundation must be designed so that the one off large event can be sustained by the structure/foundation without any appreciable movement.The foundation must be designed with sufficient margin that over time there is no degradation of the response due to the cyclic loading applied.[4]. This work had shown satisfactory correlation with a variety of different pile structures being researched. Other notable researchers who have done investigations on offshore foundations, especially foundations for wind turbines include [5], [6], [7], [8], [9], [10], [11].

1.1 Site investigation and foundation design

In pile foundation design, we carry out site investigation in order to build a reliable foundation. The knowledge of the soil condition existing at the site of construction of any sizeable structure helps to sustain a safe and economical design. On site, soil investigation will be performed to identify the various soil strata and then corresponding physical and engineering properties. The first thing to do in site investigation is reconnaissance. This is to review all available geophysical data and soil boring data as might be available in engineering files, literature or government files. This action is to help identify potential problems and to aid in planning subsequent data acquisition phases of the site investigation.

1.2Sea bottom survey The major reason of a geophysical survey in the vicinity of the site is to provide data for a geologic assessment of foundation soils and surrounding areas that can affect the site. The geophysical data provide evidence of slumps, scarps, irregular or rough topography, mud volcanoes mud lump collapse features, sand waves, slide, faults, diapers' erosion surfaces, gas bubbles in the sediments, gas seeps.

1.3soil investigation and testing The soil sampling and testing programme should be carried out after reviewing the geophysical results. On site soil investigation should include one or more soil borings which enables us to get soil samples suitable for engineering property testing. As a minimum requirement the foundation investigation for pile supported structure should provide the soil engineering property data needed to calculatethe following parameters (a) axial capacity of piles in tension and compression, load deflection characteristics of axially and laterally loaded piles, driveability characteristics and mud mat bearing capacity.Real life geotechnical dataset from the Niger Delta was made available for this project by the industry. In addition, the results of the sea bottom survey were also made available. All these will help to simulate a real life situation in the design of the pile foundation.The data is given below:

Table 1 Typical Geotechnical dataset for the Niger Delta area of Nigeria

Penetration Below Seafloor [m]	Submerged Unit Weight [kN/m^3]	Undrained Shear Strength [kPa]	Soil Sensitivity
0	3.3	1	4.5
1	3.3	7	4.5
2	3.3	4	3.0
7	4.0	10	3.0
11	4.0	17	2.5
13	4.0	17	2.5
20	4.0	32	2.5

Geophysical survey report: Geophysical surveys reveal pockmarks, gas chimneys, certain outcrops, some disturbed sediments, troughs and fault lines. Sub-bottom profiling reveals even some shallow gas occurrence. You can assume these seabed anomalies in your analysis as they will greatly influence the subsea layouts and drill centre locations.

Soil condition

- Soft, high plasticity, clays with high water contents.
- Uncharacteristically high friction angles (undisturbed)

Generic soil properties

- Yield stress ratio R – 2
- Plasticity index PI – 100%
- Friction angle Ø' - 35˚
- Interface friction angle: δ - 20˚

Methodology

II. The design of pile foundation

The pile foundation should be designed to carry static, cyclic and transient loads without excessive deformations or vibrations in the platform. Special attention will be given to the effects and cyclic and transient loading on the strength of the supporting soils as well as the structural response of the piles

2.1 Types of pile foundations

There are many types of pile foundations used to support offshore structures. Out of the different types that are briefly discussed I have chosen the driven piles.

2.2 Driven piles The open ended piles will be used as the foundations for the offshore storage tank. These piles will be driven into the sea floor with impact hammers which use steam, diesel fuel, or hydraulic power as the source of energy. The pipe wall thickness will be designed adequately to resist axial and lateral loads as well as the stresses during pile driving.

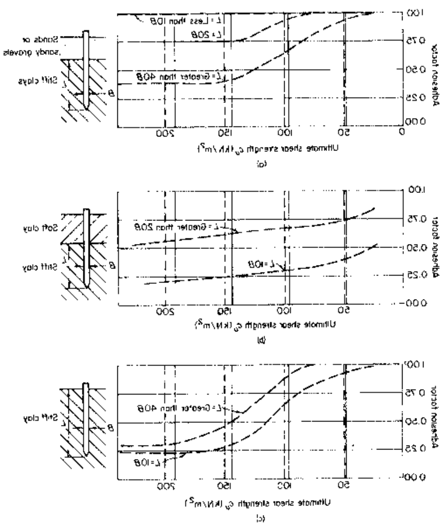
2.3Drilled and grouted piles Drilled and grouted piles are used in soils which hold an open hole with or without drilling mud. There are two different types of drilled and grouted piles. These are

- Single-stage. For this type of drilled and grouted pile, an oversized hole is drilled to the required penetration, then a pile is lowered into the hole and the annulus between the pile and the soil is grouted. The installation of this type of pile can

only take place in soils which will hold an open hole to the surface.

- Two stage. This type of drilled and grouted piles consists of two concentrically placed piles grouted to become a composite section. The pile will be driven to a penetration which has been determined to be achievable with the available equipment below which an open hole can be maintained. This outer will now become the casing for the next operation which is to drill through it to the required penetration for the inner or ‘‘insert’’ pile. This insert pile will now be lowered into the drilled hole and the annuli between the insert pile and the soil and the two piles are grouted.

2.4Belled pilesBELLED PILES: In this case bells will be constructed at the tip of the piles to give increased bearing and uplift capacity through direct bearing on the soil. The drilling of the bell is carried out through the pile by under reaming with an expander tool.**2.5Foundation size** In the design of a pile foundation the following items will be considered, diameter, penetration, wall thickness, type of tip, spacing, number of piles, geometry, location mudline restraint, material strength, installation method.



2.6Deflections and rotation The deflections and rotation of individual piles and total foundation will be analysed at different locations which will include pile tops, points of contraflecture, mudline, etc. Deflections and rotations should not exceed serviceability limits which would render the structure inadequate for its intended function.

2.7 Pile penetration Pile design will ensure that pile penetration should be sufficient to develop adequate capacity to resist the maximum computed axial bearing and pull out loads with an appropriate factor of safety.The pile penetration for soft clay with undrained shear strength of 32KPa will require a deep foundationDeep foundations of pile structure are used to

- Transmit load through unsuitable soils e.g. peat, landfill, soft clays.
- Transmit load through soils that are too weak to support the load.
- To reduce settlement.
- To make use of underground space (e.g. basement structure)
- To avoid geohazards

2.8 Calculation of skin friction and end bearing in cohesive soils
Load is transmitted to the ground through the end bearing and the skin friction.
Skin friction: This is the interface friction between the surface of the piles and the ground.
From the API code (1993) the shaft friction f, at any point along the pile can be calculated by this equation given below:

$$f = \alpha\, c \quad (1)$$

where:
α = a dimensionless factor
c = undrained shear strength of the soil at the point in question
The factor, α, can be computed by the equations

$$\alpha = 0.5\psi^{-0.5} \quad \psi \leq 1.0$$
$$\alpha = 0.5\psi^{-0.25} \quad \psi > 1.0$$

With the constraint that, $\alpha \leq 1.0$
Where:

ψ = c/po’ for the point in question

po’ = effective over burden pressure at the point in question (kpa)

Nevertheless, from the API standard for highly plastic clays such as found in the Gulf of Mexico and West Africa, f may be equal to c for under consolidated clays (clays with excess pore pressure undergoing active consolidation), and consolidated clays. Therefore α, can be taken as1.0.

2.9 Ultimate skin friction

The ultimate skin friction:
Q_f = fx A_S = α x c x A_S (2)

Where As = Surface area of shaft over embedded depth within clay giving support to the pile or within an individual soil layer. $A_S = 2\pi rh$

A table of the skin friction for the different points on the pile can be generated as given below:

2.10 End bearing It is the ground capacity at the base of the piles. For the pile end bearing in cohesive soils, the unit end bearing q in (kpa), may be computed by the equationThe end bearing: q = N c (3)Where N = 9 And c = undrained shear strength**2.11 Ultimate end bearing capacity**The ultimate end bearing capacity:Q_p= q x A_p= N x c x A_p(4)Where A_p= Area of base of pile which is πr^2

Table 2; Computation of end bearing

Penetration Below Seafloor [m]	Undrained Shear Strength [kPa]	End bearing, q (kpa)	Skin friction, f (kpa)
0	1	9	0
1	7	63	7
2	4	36	4
7	10	90	10
11	17	153	17
13	17	153	17
20	32	288	32

The skin friction on the piles at the surface of the sea floor is zero because there is no penetration of the piles into the soil. The skin friction on the piles below the sea floor up to two meters is negligible and may be discarded if need be.

2.12 Ultimate bearing capacity

The choice of wall thickness, diameter and height of pile is by iterative method. A preliminary pile diameter is chosen for the initial pile design to obtain the pile capacity. This obtained result is used to match the axial load. It is done iteratively until the pile capacity is able to bear the axial load. A pile diameter of 12" (0.3048m) is chosen as the preliminary pile diameter, while a length of 20 meter embedment as the pile heightThe first diameter chosen was 12" and the results obtained are given below

Table 3; Determination of ultimate end bearing capacity and skin friction for 12'' diameter pile

End bearing, q (kpa)	ultimate end bearing capacity,Q_p	Skin friction, f (kpa)	Surface Area, A_S	Ultimate skin friction,Q_f
9	0.6561	1	0	0
63	4.5927	7	0.957	6.699
36	2.6244	4	0.957	3.828
90	6.561	10	4.785	47.85
153	11.153	17	3.828	65.076
153	11.153	17	1.914	32.538
288	20.995	32	6.699	214.368
	57.73			**370.359**

The ultimate bearing capacity of piles is determined by the equation:Q_d= Q_f+Q_p= fx A_S +q x A_p(5)

= 57.3 + 370.359 = **427.659KN**

From the results obtained, the 12" diameter pile cannot be appropriate for the pile foundation.This is because it will call for a large number of piles to be embedded into the ground.The second diameter chosen was 24" and the results obtained are given below.

Table 4; Determination of ultimate end bearing capacity and skin friction for 24'' diameter pile

End bearing, q (kpa)	ultimate end bearing capacity,Q_p	Skin friction, f (kpa)	Surface Area, A_S	Ultimate skin friction,Q_f
9	0	1	0	0
63	0	7	1.914	13.398
36	0	4	1.914	7.656
90	0	10	9.570	95.70
153	0	17	7.656	130.152
153	0	17	3.828	65.0576
288	84.009	32	13.398	428.736
	231.025			**740.699**

The ultimate bearing capacity of piles is determined by the equation:

$Q_d = Q_f + Q_p = f x A_S + q x A_p$(6) The ultimate end bearing capacity is obtained from the area from the end of the pile at the twenty meter depth.

= 84.009 +740.699

= **824.708KN**

From the result obtained the 24" diameter pile is appropriate for the pile foundation. This is because the number piles that will be able to withstand the axial load are minimal.

2.13 Pile groups

A group of piles such that the spacing results in interaction between the loads transfer from each pile.

When piles are arranged in closely spaced groups the mechanism of failure is different from that of a single pile.

Piles and the soil contained with the group act together as a single unit.

Factors dictating whether the piles will behave as a group include spacing, size, shape and length of piles.

Consolidation settlement of a pile group will be greater than that of a single pile carrying the same working load as each in a group.

2.14 Number of piles and pile layout pattern (considering only the axial load)

Total service pile vertical load: $P = P_D+P_L$(7)Where
P_D = Pile dead load = weight of the storage tank + the weight of the four columns
P_L = Pile live load = weight of the petroleum product
Estimated number of piles: $n = P÷P_c$(8)
Pile dead load: P_D=1303.32KN + 29016.80KN = 30320.13KN Pile live load: P_L = 35125.13042KN
Total service pile vertical load, P = 30320.13KN + 35125.13KN = 65445.26KN
Allowable pile compression capacity: P_c=824.7KN
Thecompression capacity is the combination of skin friction and the end bearing capacity. Estimated number of piles: $n = P÷P_c$ = 65445.26KN÷824.7KN
Estimated number of piles: n = 79.3piles = 80 piles
Axial load per pile = p÷n(9)

=65445.26KN÷80Piles=818.06kN

2.15Pile layout pattern

Pile under pile cap should be laid out symmetrically in both directions. The column or wall on pile cap should be centred at the geometric centre of the pile cap in order to transfer load evenly to each pile. Examples of pile layout patterns are shown below:

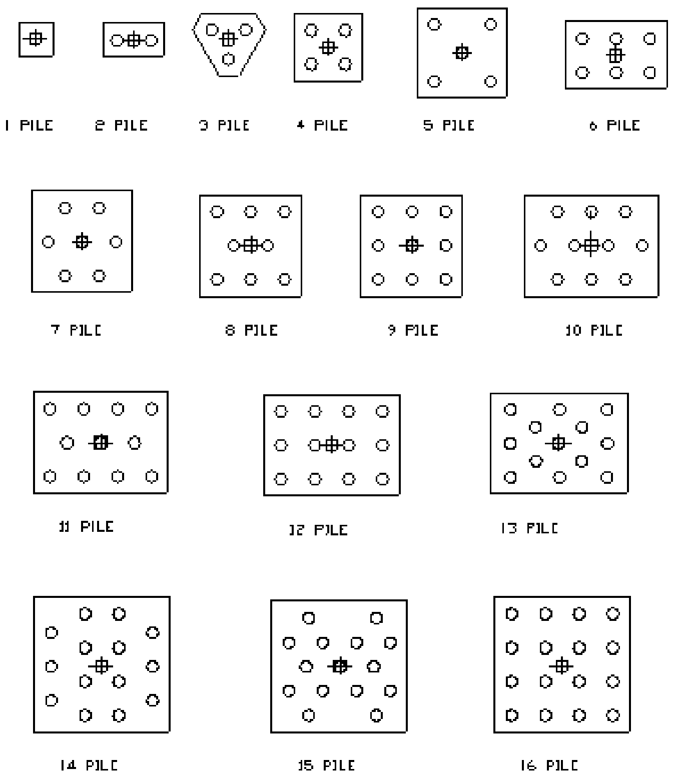


Figure 1

Different pile layout pattern

From the pile foundation design, eighty (80) piles of twenty four inch diameter (24 inches or 0.6096 meters) and of a height of twenty meters will be required to form the foundation of the tank. From the above pipe layout pattern the twenty piles per column layout pattern was chosen. This will provide four columns to stand the tank.

2.16 Pile spacing In general, spacing between piles should be 3 times of the pile diameter in order to transfer load effectively to the soil. If the spacing is less than 3 times of the pile diameter, the pile group settlement and bearing capacity should be checked

Table5: correlation of pipe diameter to spacing

Pile diameter	12"	14"	16"	18"	20"	22"	24"
Pile spacing	3'-0"	3'-6"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"

The minimum pile spacing for this project is given as,
Minimum spacing of pile: s = 24" (0.6096m) x 3 = 6' (1.828m)

2.17Pile cap The structure that sits on top of a pile group that transmits the load from the structure to the pile group is referred to as the pile cap

2.18 Minimum wall thickness The minimum wall thickness of the pile can be calculated using formulas or tables from the API CODE .

$t = 0.25 + D/100$ (10)

Metric formula $t = 6.35 + D/100$ (11)

where: t = wall thickness D = diameter in (mm)Therefore, $t = 6.35 + 610/100 = 12.45$millim

Table 5; Minimum pile wall thickness from API

PILE DIAMETER		NORMINAL WALL THICKNESS , t	
inches	millimeter	inches	millimeter
24	610	$^{1}/_{2}$	13
30	762	$^{9}/_{16}$	14
36	914 $^{5}/_{8}$	16	
42	1067	$^{11}/_{16}$	17
48	1219	$^{3}/_{4}$	19
60	1524	$^{7}/_{8}$	22
72	1829	1	25
84	2134	1 $^{1}/_{8}$	28
96	2438	1 $^{1}/_{4}$	31
108	2743	1 $^{3}/_{8}$	34
120	3048	1 $^{1}/_{2}$	37

With the pile diameter chosen as 914 millimetre, then the corresponding pile wall thickness on the API recommended practise will be 16 millimetre.

Conclusion

The pile foundation is designed to sustain lateral loads, especially static load and even cyclic loads. A safety factor is introduced to increase the lateral load to take care of overload cases.

For static lateral loads the ultimate unit lateral bearing capacity of soft clay, Pu from the API CODE has been found to vary between 8c and 12c exempting shallow depths where failure occurs in a different mode due to minimum overburden pressure. Therefore the different lateral bearing capacity for soft clay at different depths in the Niger Delta is calculated and tabulated below. An average of 8c is taken for this project where c is the undrained shear strength (KPa) is taken for the project

Undrained Shear Strength [kPa]	**Lateral bearing capacity(kpa)**
1	10
7	70
4	40
10	100
17	170
17	170
32	320

The total Lateral bearing capacity at meters below sea floor is

10 + 70 + 40 +100 = 220 MPa

The ultimate lateral bearing capacity of the piles on the clay will not be accounted for because this will include the horizontal cyclic loads of wave force, current and wind load on the embedded piles. In addition, the effect of vertical cyclic loads on the embedded piles will be included such as the varying life loads (petroleum products). All these were not considered because of time constraint for the project.The British standard requires that the number of piles to be embedded into the soil obtained from the design calculations must be multiplied by a factor of three or the heights of the piles be multiplied by also a factor of three as a

safety measure against future settlement failure or bearing capacity failure.

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